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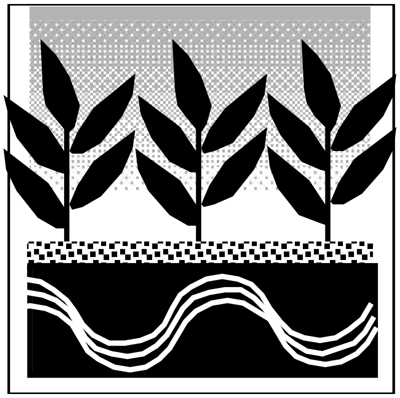

Understanding pesticide persistence and mobility for groundwater and surface water protection

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This publication is intended to provide pesticide advisors, pesticide users, and resource managers with an introduction to the fate of pesticides in the environment. This document addresses the potential for pesticides to reach groundwater and surface water and is part of a package of training materials designed to assist in making pesticide use decisions that protect water quality. Other documents in the package are listed on the last page.

The goal of these documents is to assist pesticide users and resource managers in making site-specific pest management decisions that give greater consideration to the protection of water resources.

Many factors govern the potential for groundwater or surface water contamination by pesticides. These factors include: properties of the soil, properties of the pesticides, hydraulic loading on the soil, and crop management practices. This document focuses mainly on the second factor, properties of pesticides that affect their fate in the environment and the environmental and site conditions that influence these properties.

Figure 1 shows many of the possible fate processes for a pesticide. These processes can be grouped into those that affect **persistence**, including photodegradation, chemical degradation and microbial degradation, and those that affect **mobility**, including sorption, plant uptake, volatilization, wind erosion, runoff, and leaching.

Pesticide persistence and mobility are influenced by the properties of the pesticide. The properties of a pesticide are, in turn, influenced by the soil environment, site conditions, weather, and application method (Figure 2).

Pesticides behave in somewhat predictable ways in the environment. Some of the most important properties of a pesticide that can be used to predict environmental fate include **half-life**, soil **sorption coefficient**, **water solubility**, and **vapor pressure**. Other useful parameters for predicting environmental fate include the Groundwater Ubiquity Score, or **GUS**, which is a number derived from the half-life and the sorption coefficient, and the **Henry's law constant**, which is a number derived from the water solubility and the vapor pressure.

Table 1 on page 3 lists seven pesticides and the properties and parameters useful for predicting environmental fate. It will be used throughout this document to help illustrate the text.

Figure 1.—Potential pesticide fates.

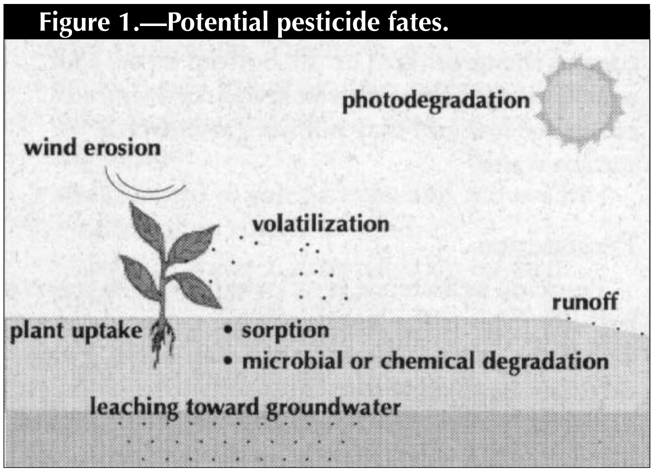

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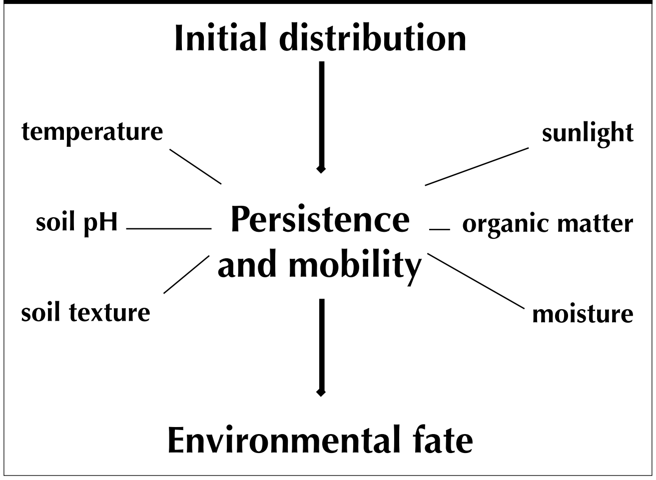
Figure 2.—Factors that influence pesticide fate in the soil.



Initial distribution

The fate of a pesticide in the environment is influenced by the initial pesticide distribution. Initial distribution describes the proportion of pesticide that is on or in the air, soil, water, plants, and animals after application. This amount is determined by the formulation, method, and rate of application, as well as topography, amount and type of vegetation and groundcover, and weather conditions. With time, the pesticide may be redistributed within the application site or may move off site—beyond the edge of the target area or the bottom of the root zone. Pesticides that move off site represent an economic loss and may pollute groundwater or surface water.

Persistence

Pesticide persistence often is expressed in terms of **half-life**. This is the length of time required for one-half of the original quantity to break down. Pesticides can be divided into three categories based on half-lives: *nonpersistent* pesticides with a typical soil half-life of less than 30 days, *moderately persistent* pesticides with a typical soil half-life of 30 to 100 days, or *persistent* pesticides with a typical soil half-life of more than 100 days.

In Table 1, the pesticides are organized according to their half-life. Malathion, 1,3-dichloropropene, and dicamba salt are nonpersistent. Benomyl and diuron are moderately persistent. Bensulide and prometon are persistent.

The half-life values in Table 1 represent "typical" soil half-life. Persistence in soil may vary greatly because degradation is influenced by a number of factors, many of which are determined by specific local conditions.

Ultimately, the degradation products of any organic chemical will be water, carbon dioxide, and minerals. However, intermediate degradation products of some pesticides are of concern for health or environmental reasons. In these cases, half-life values should be determined for the intermediate products.

Pesticides degrade by microbial activity, chemical activity, or sunlight. All three processes may participate in the breakdown of a single pesticide. The rate of degradation depends on pesticide chemistry, as well as on environmental conditions. Distribution between foliage and soil, as well as temperature, soil and water pH, microbial activity, and other soil characteristics may affect pesticide persistence. The half-life values in Table 1 represent persistence in soil. In general, pesticide residues on canopy foliage or ground cover tend to be less persistent than soil residues.

Microbial degradation is the breakdown of chemicals by microorganisms (Figure 3). It occurs when fungi, bacteria, and other soil microorganisms use pesticides as food or consume pesticides along with other substances. Soil organic matter, texture, and site characteristics—such as moisture, temperature, aeration, and pH—all affect microbial degradation. Microbial activity usually is greatest in warm, moist, well-aerated soils with a neutral pH. Microbial degradation is mediated by enzymes. The rate of most reactions catalyzed by enzymes tends to double for each 10°C increase in temperature between 10 and 45°C (50 to 113°F). Enzyme

Figure 3.—Microbial and chemical degradation.

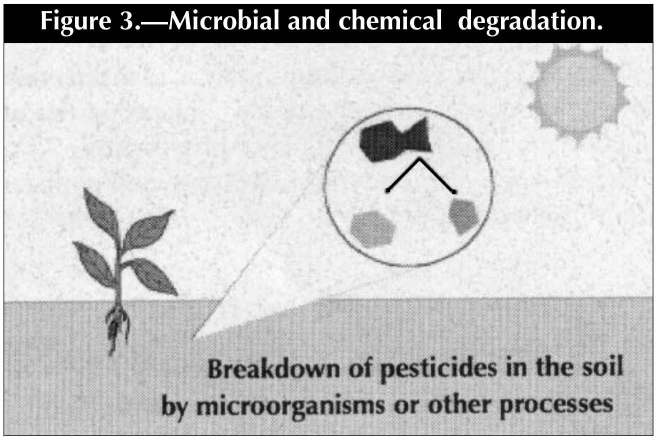


Table 1.—Common name, half-life, sorption coefficient (K_{oc}), GUS value, pesticide movement rating, water solubility, vapor pressure index, and Henry's law index for seven pesticides.

Pesticide	Half-life (days)	K_{oc}	GUS	Movement rating	Solubility (mg/L)	Vapor pressure index (mm Hg x 10^7)	Henry's law index (Kh x 10^9)
Malathion	1	1,800	0.0	extremely low	130	80	1000
1,3-Dichloropropene	10	32	2.49	moderate	2,250	290 billion	77 billion
Dicamba salt[1]	14	2	4.24	very high	400,000	0	0
Benomyl	67	1,900	1.32	low	2	0.001	0.78
Diuron	90	480	2.58	moderate	42	0.69	21
Bensulide	120	1,000	2.08	moderate	5.6	8	3,058
Prometon[1]	500	150	4.92	very high	720	77.3	130

[1] *Dicamba salt is a weak acid; prometon is a weak base. Sorption and solubility of both may be affected by soil pH.*

activity is greatly reduced above and below these temperatures. Microbial degradation occurs at a higher rate in the surface soil horizons, particularly in areas with high organic matter. Usually, the rate decreases with depth in the soil, where conditions such as moisture, temperature, and aeration are less favorable for microbial activity.

Chemical degradation occurs when a pesticide reacts with water, oxygen, or other chemicals in the soil. Chemical degradation also can occur in the air or on foliage. As soil pH becomes extremely acidic or alkaline, microbial activity usually decreases. However, these conditions may favor rapid chemical degradation.

Photodegradation is the breakdown of pesticides by sunlight. All pesticides are susceptible to photodegradation to some degree. The intensity and spectrum of sunlight, length of exposure, and properties of the pesticide affect the rate of photodegradation. Pesticides that are applied to foliage or to the soil surface are more susceptible to photodegradation than pesticides that are incorporated into the soil. Glass filters out much of the ultraviolet light, which has the greatest potential to photodegrade pesticides. Therefore, pesticides may degrade faster inside plastic-covered greenhouses than inside glass greenhouses.

Mobility

Pesticide mobility may result in redistribution within the application site or movement of some amount of pesticide off site.

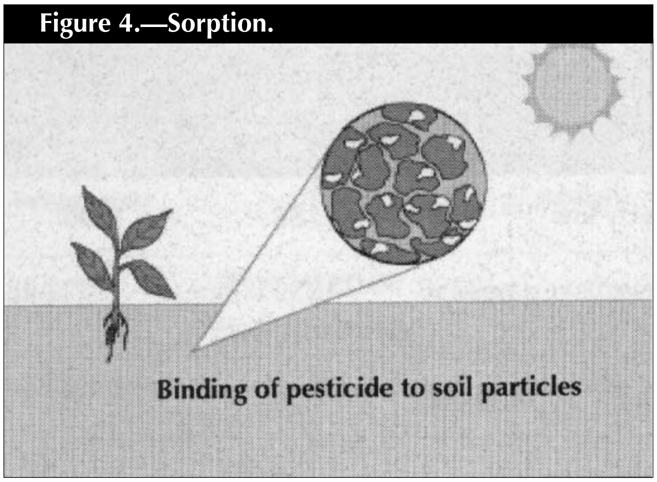
After application, a pesticide may:

- Attach (sorb) to soil particles, vegetation, or other surfaces and remain near the site of deposition
- Attach (sorb) to soil particles and move with eroded soil in runoff or wind
- Dissolve in water and be taken up by plants, move in runoff, or leach
- Volatilize or erode from foliage or soil with wind and become airborne

Mobility is affected by the pesticide's sorption, water solubility, and vapor pressure. Mobility also is influenced by environmental and site characteristics including weather, topography, canopy, and ground cover; and soil organic matter, texture, and structure.

Sorption describes the attraction between a chemical and soil, vegetation, or other surfaces. However, sorption most often refers to the binding of a chemical to soil particles (Figure 4). Pesticides that are sorbed to soil particles are more likely to

Figure 4.—Sorption.



remain in the root zone where they may be available for plant uptake and microbial or chemical degradation. However, pesticides that are strongly sorbed to soil usually are less available for microbial degradation and plant uptake. Pesticides that sorb weakly to soil particles are more likely to move through the soil profile with infiltrating water.

Sorption is determined by the chemical characteristics of the pesticide. The specific mechanisms for the sorbing of a chemical to the soil are not easily defined. Numerous mechanisms may operate in a particular situation, including strong or weak ionic attraction, hydrophobic attraction, and hydrogen-bonding. For pesticides that are weak acids or bases, such as dicamba salt and prometon, sorption is influenced by the pH of the soil. Weak acid or base pesticides may carry a positive or negative charge, or no charge depending on pH.

Sorption also is influenced by soil moisture, organic matter content, and texture. Pesticides are more readily sorbed onto dry soil because water competes with pesticides for binding sites in moist soil. Organic matter and clay particles both have plenty of surface area and are chemically active. Soils high in clay or organic matter, or both, have a high potential to sorb pesticides. Clay content also is important for holding organic matter in the soil. Sand particles provide less surface area for sorption. Pesticides are more likely to move away from the point of application in sandy soils. Soils that have an organic layer, such as crop residues or thatch in turfgrass, may strongly sorb pesticides and reduce their mobility.

The sorption of a particular pesticide to a soil is measured in a laboratory by mixing water, pesticide, and soil. After equilibrium has been reached, the amount of pesticide remaining in solution is measured. The concentration of pesticide sorbed to the soil in the mixture is divided by the pesticide concentration still in solution. This yields the **distribution coefficient**, (**K_d**). A low distribution coefficient indicates that more of the pesticide is in solution; a higher value indicates that the pesticide is more strongly sorbed to soil.

The distribution coefficient determined in the laboratory will vary depending on the ratio of soil to water and the chemical properties of both the pesticide and the soil. For this reason, a different number, the **sorption coefficient** (**K_{oc}**), is used to compare the relative sorption of pesticides. K_{oc} is the distribution coefficient divided by the amount of organic carbon in the soil. (Soil organic carbon is directly proportional to soil organic matter, which is primarily responsible for a soil's sorption properties.)

The higher the K_{oc} value, the more strongly the pesticide is sorbed, and therefore, the less mobile it is.

K_{oc} values for seven pesticides are listed in Table 1. Among these pesticides, dicamba salt has the lowest sorption coefficient ($K_{oc} = 2$) and benomyl has the highest ($K_{oc} = 1900$). Therefore, dicamba salt would be the most mobile, and benomyl would be the most tightly bound.

The Groundwater Ubiquity Score, or **GUS**, frequently is used to rate pesticides for their potential to move toward groundwater. The GUS is a number that relates pesticide persistence (half-life) and sorption (K_{oc}) in soil. A pesticide with a short half-life and high K_{oc} will have a lower GUS than a pesticide with a long half-life and low sorption coefficient.

Table 2.—Pesticide movement ratings and their GUS equivalents.

GUS Value	Pesticide Movement Rating
less than 0.1	Extremely low
0.1 – 1.0	Very low
1.0 – 2.0	Low
2.0 – 3.0	Moderate
3.0 – 4.0	High
more than 4.0	Very high

At Oregon State University, researchers use the **pesticide movement rating** to describe the potential for a pesticide to move toward groundwater. The pesticide movement rating is derived from the GUS by assigning a rating to a range of GUS values, shown in Table 2.

Referring back to Table 1, malathion, with a short half-life and high sorption coefficient, has the lowest movement rating. Prometon has a very high movement rating, based on its very long half-life and relatively low sorption. Interestingly, dicamba salt has the same movement rating as prometon, even though the two pesticides have very different half-life and sorption properties. Dicamba's high rating is influenced by its very low tendency to bind to soil.

Water solubility describes the amount of pesticide that will dissolve in a known amount of water. It usually is measured in milligrams per liter of water (mg/L) or parts per million (ppm). Referring to Table 1 again, dicamba salt has the highest solubility, 400,000 mg/L. Benomyl is the least soluble of these seven pesticides. Benomyl's solubility is 2 mg/L.

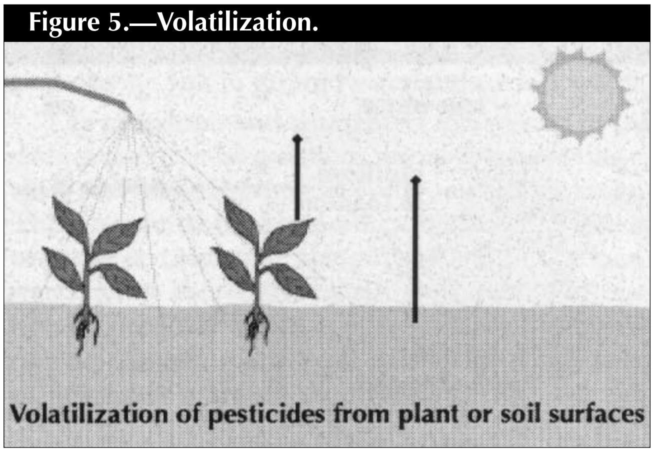
These values are most useful as a means of comparison. How much actually dissolves in the field may differ because solubility is affected by temperature and the presence of other chemicals. Solubility of those pesticides that are weak acids or bases also is influenced by pH.

Highly soluble pesticides are more likely to be moved—within the site or off site—by runoff or leaching.

The degree of **plant uptake** is determined partially by the pesticide's water solubility. It also is affected by adjuvants (additives) that may enhance uptake. While in solution, a pesticide can move with water on or in the soil and contribute to runoff or leaching. It also can move across cell membranes and be taken up by plants. Plant uptake of pesticides prevents runoff or leaching.

Pesticides also may volatilize (Figure 5) or be blown away by the wind (erode). **Volatilization from foliage** is determined by the pesticide's vapor pressure, which is affected by temperature. The higher the temperature, the greater the volatilization. Leaf surface temperatures can be much higher than nearby air temperatures, particularly at midday on cloudless days when the greatest amount of solar radiation reaches the leaf. Pesticides on foliage are most susceptible to volatilization immediately after application because over time, pesticides become incorporated into surface waxes.

Figure 5.—Volatilization.



In Table 1, dicamba salt, benomyl, diuron, and bensulide all are relatively nonvolatile; 1,3-dichloropropene is highly volatile.

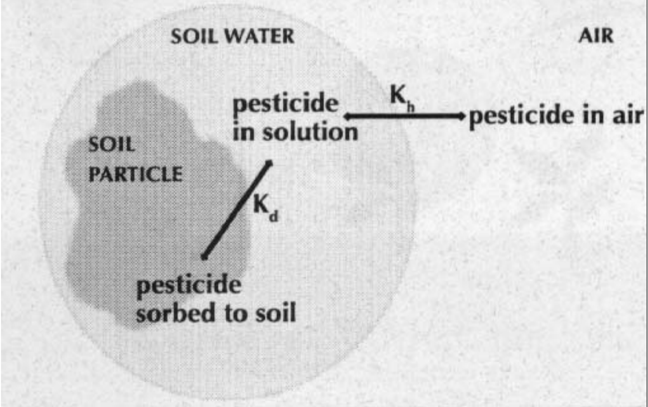
To make the numbers in Table 1 easier to read, the vapor pressure values have been multiplied by 10^7 (**vapor pressure index**). Take this into account before you compare them to vapor pressures given in other materials.

In general, pesticides with vapor pressure index values of less than 10 have a low potential to volatilize. Pesticides with vapor pressure index values greater than 1,000 have a high potential to volatilize.

Volatilization from moist soil is determined by the moisture content of the soil, and by the pesticide's vapor pressure, sorption, and water solubility. Volatilization from dry soil is determined by the pesticide's sorption and vapor pressure.

Volatilization from moist soil is described by K_h, the **Henry's law constant**. K_h is defined as the concentration of pesticide in air divided by the concentration in water. This value can be calculated using the pesticide's vapor pressure and solubility. K_h characterizes the tendency for a pesticide to move between the air and the "soil water." The higher the Henry's law constant, the more likely that a pesticide will volatilize from moist soil.

Figure 6.—Distribution coefficient (K_d) and Henry's law constant (K_h).



Since sorption will affect the amount of pesticide in the soil water, the tendency to volatilize from moist soil depends on both the Henry's law constant and the distribution coefficient, K_d (Figure 6).

During periods of direct sunlight, temperatures at the soil surface may be much higher than surrounding air. This can increase volatilization at the soil surface.

Of the pesticides in Table 1, dicamba salt, benomyl, and diuron have a low potential to volatilize from moist soil; 1,3-dichloropropene and bensulide have a higher potential to volatilize. To make the numbers in Table 1 easier to read, the Henry's law constant values have been multiplied by 10^9 (**Henry's law index**). Take this into account before you compare them to values in other publications.

In general, pesticides with Henry's law index values of less than 100 have a low potential to volatilize from moist soil. Pesticides with Henry's law index values above 10,000 have a high potential to volatilize.

Airborne pesticide residues are subject to a variety of degradation processes, including photodegradation, oxidation, and hydrolysis. They often are degraded rapidly in the atmosphere. However, stable airborne pesticide residues and their degradation products may move from the application site and be deposited in dew, rainfall, or in dust. This may result in pesticide redistribution within the application site or movement of some pesticide off site.

Runoff is the movement of water over a sloping surface (Figure 7). Runoff can carry pesticides dissolved in water and pesticides sorbed to eroding soil. If irrigation or heavy rainfall shortly after application induces runoff, some pesticide may move off site. Heavy rainfall or overhead irrigation soon after application also may dislodge pesticide residues on foliage, creating loss with runoff. With time, residues on foliage are less likely to be washed off as they become incorporated in surface waxes.

Leaching is the removal of soluble materials by water passing through the soil (Figure 8). Groundwater contamination occurs when pesticides move with infiltrating water through the soil profile to the water table. The closer the water table is to the surface, the greater the likelihood that it may become contaminated.

Pesticides that are highly water soluble, relatively persistent, and not readily sorbed to soil particles (low K_{oc} or low distribution coefficient) have the greatest potential for movement.

Figure 7.—Runoff.

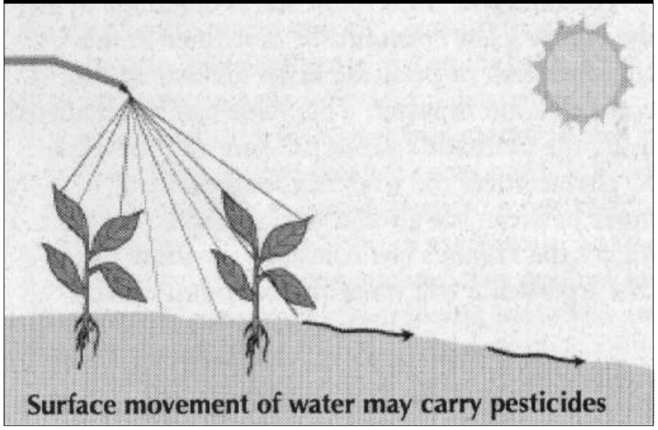
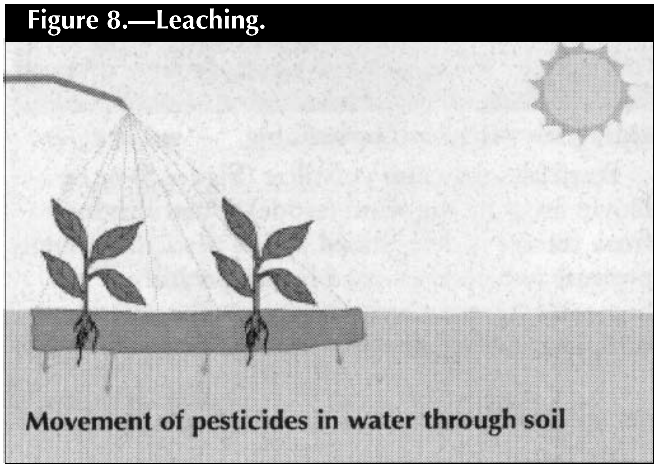


Figure 8.—Leaching.



Summary

Any pesticide will remain in the environment for some amount of time and move to some degree following application. To make sound pest management decisions, pesticide users, advisors, and resource managers should have an understanding of the fate of pesticides in the environment.

Pesticide fate in the environment depends on the rate, timing, and method of application, as well as a variety of dynamic and interrelated physical, chemical, and biological processes. These processes are influenced by environmental conditions that are often site-specific. Careful consideration of these fate processes and their interactions is necessary to evaluate the risk to groundwater and surface water.

The properties and parameters introduced in this document are most useful as initial risk screening tools and can assist in developing relative rankings. They cannot be used to predict the absolute amount of pesticide that may enter groundwater or surface water. More thorough evaluations require information on pesticide fate in conjunction with information on climate, specific soil and site characteristics, management practices, and toxicology.

Notes

For more information

Contact your county office of the OSU Extension Service for more information about protecting your groundwater and surface water from potential contamination by pesticides. For information about specific chemicals and their properties, contact OSU Environmental and Molecular Toxicology at the address below.

Ordering information

Extension publications

This publication and its companion pieces, EM 8559, *How soil properties affect groundwater vulnerability*, $1.00, and EM 8560, *Site assessment for groundwater vulnerability to pesticide contamination,* $1.50, are available from:

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Further reading

Gustafson, D.I. 1989. Groundwater Ubiquity Score: A simple method for assessing pesticide leachability. *Environmental Toxicology and Chemistry*. Volume 8, pp. 339-357. This journal is available at university libraries.

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